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Introduction

The project aims to develop a battery of tests to diagnose visual dysfunctions in cognitively impaired observers based on their oculomotor reflexes. The oculomotor reflexes provide a simple and robust method to study vision in passive/immature/impaired observers. For example, oculomotor reflexes are widely used to study vision in infants and in marketing research. The proposed method is versatile, applies to a wide range of visual mechanisms, and can provide both qualitative (yes/no) and quantitative (degree) estimates of the visual loss. The project embodies a full research and development cycle, from establishing the most effective stimuli for various kinds of visual dysfunctions to the design of a computerized testing kit suitable for use by non-specialists. After a short training course, the kit could be used at army bases and local hospitals to make a quick initial diagnosis.

Body

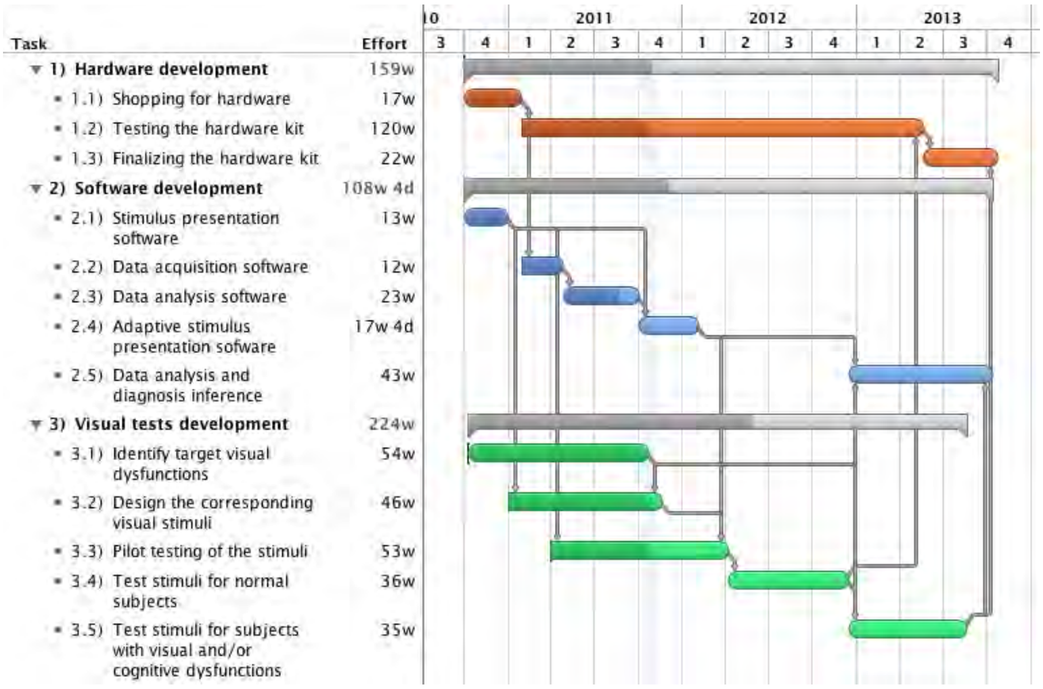

Figure 1: Gantt chart for the project.

As specified in the Statement of Work, the main goal of the first 12 months of the project was to design effective stimuli allowing the oculomotor reflexes to be used as diagnostic tools for various visual dysfunctions. The three reflexes proposed for this project (optokinetic reflex, pupillary reflex, orienting reflex) form a complementary set. For example, our preliminary data demonstrated that optokinetic reflex in response to drifting gratings is an effective tool for testing various low-level visual mechanisms, such as visual acuity, contrast sensitivity, color, and depth sensitivities. On the other hand, orienting and pupillary responses to salient stimuli can be used to test higher-order visual functions, such as shape perception, face recognition,

visual memory, etc. Even if the subject's eye movements are impaired by the injury, the pupillary reflex alone can be used as a qualitative diagnostic tool for both the low-level and the high-level visual functions.

Figure 1 shows a Gantt chart indicating project tasks and their current state of completion. Overall, all the current goals were met: we selected and purchased all the necessary hardware for the project, identified common visual dysfunctions, designed pilot stimuli testing for these dysfunctions, and developed the necessary software to present the stimuli, capture the eye-tracking data, and analyse it for the relevant eye-events. These tasks are described in detail in the following sections.

Hardware development

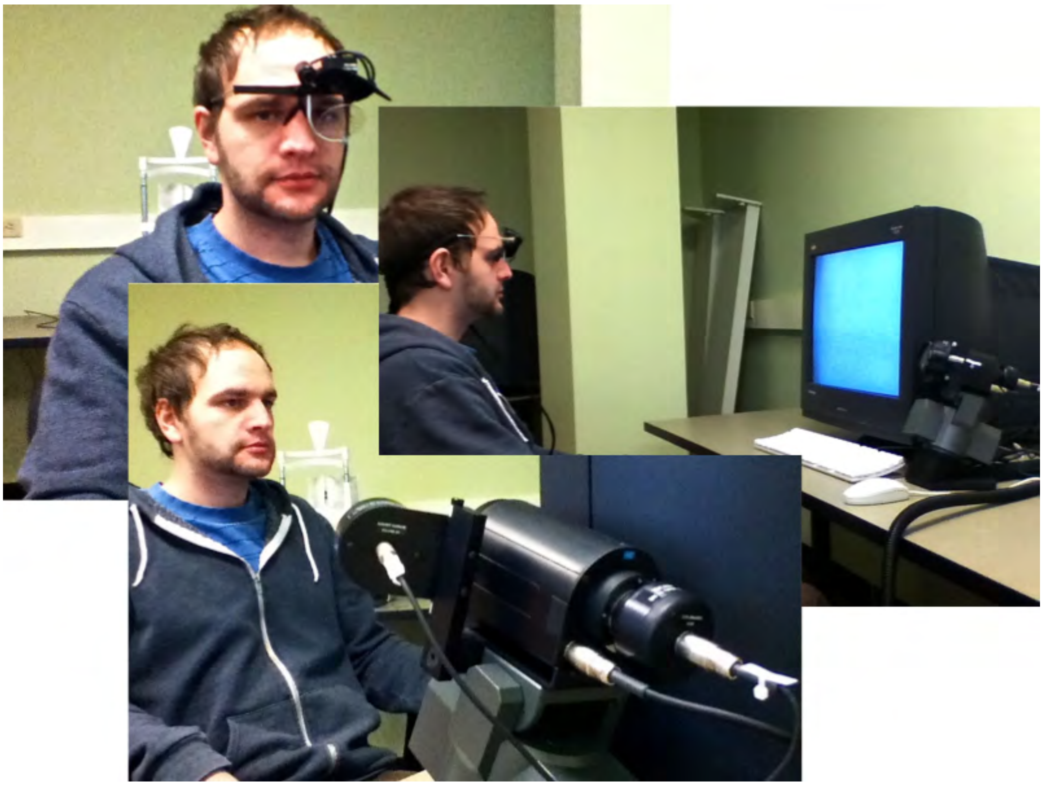

Figure 2: Two ISCAN Inc. eye-trackers used for the project. The head-mounted unit is mounted on a safety goggles frame. The remote unit is positioned next to the monitor.

We primarily investigated different models of eye-trackers in the first

quarter. The goal was to find the model best suited for the project, i.e., portable, and well suited for experimental work with cognitively impaired subjects. Other search parameters included programming interface capabilities, ease and speed with which hardware customizations could be made, and the overall cost. After investigating several eye-tracker models being used on Northeastern University campus and visiting local manufacturers of eye-tracking equipment we purchased two video-based eye trackers from ISCAN Inc. (based locally in Woburn, MA): one in remote and one in head-mounted configuration (Figure 2). This allowed us to test both eye-tracking modes and to find the one best suitable for this project.

The head-mounted version can be mounted on a goggles frame or a baseball cap. It appears to be the preferred solution and will be used for most subjects. Head-mounting the eye-tracker allows to study subjects with uncontrollable head and body movements. The remote (desktop mounted) version with automatic head tracking will be used for those subjects which might have difficulty with or might not tolerate wearing the head-mounted version. This version will also be used for measuring binocular functions for all subjects, because it allows to track both eyes simultaneously.

The eye-tracking units came with a laptop and desktop computers. The laptop computer is more portable, but currently can only be used for 120 Hz eye-tracker sampling rate. The desktop can be used for 240 Hz sampling rate, but is less portable. Pilot data indicates that 120 Hz is adequate for our purposes, but we are leaving the 240 Hz option open, because the higher sampling speed might be necessary for noisier data (subjects with droopy eyelids, thick glasses, uncontrolled head-movements, etc.).

To ensure maximum performance two computers (laptops) are used in our current hardware configuration. One computer is dedicated to controlling the eye-tracker and collecting the data. Stimulus generation, presentation, and data analysis are carried out by another computer. The two computers communicate via serial connection.

Visual tests development

In the second, third, and forth quarters we collected and analyzed pilot data for normal observers. Pilot stimuli included various drifting gratings and odd-ball images of faces, bodies, and words. Figure 3 shows some examples. The images were obtained from freely available research databases. Typical pilot session lasted 6 minutes during which 30 - 40 visual stimuli were shown. Subjects were viewing stimuli on a 21" LCD monitor from a distance of 60 - 80 cm. The head-mounted version of the eye-tracker was used for all subjects,

Figure 3: Examples of visual stimuli used for the pilot study. Drifting gratings (top left) were used to evoke optokinetic reflex, neutral and mildly offensive words (top right) were used to evoke pupillary response, images of odd-ball and mildly arousing female figures were used to evoke orienting reflex (saccades) and pupillary response.

eye-movements were sampled at 120 Hz. At this stage the data were collected off-line: recorded on a hard drive during the experimental run and analyzed after its completion. The pilot data was used to optimize the visual stimuli and to design/test eye-event filters as described below. A fragment of the pilot data for one subject is shown in Figure 4.

The stimuli were used to evoke reflex eye-movements in 26 normal observers. We received clearances from the Northeastern University IRB and MEDCOM USAMRMC for work with human subjects in March 2011. PI and his graduate students were used as subjects prior to this date. We used inexperienced observers naive to the purpose of the test: observers only knew that they were taking part in an eye-tracking experiment. The only instructions received from the experimenter were to attend to the screen. Such experimental conditions were chosen to simulate testing cognitively impaired

observers. Such observers will be tested in the final phase of the project.

Software development

Once the eye-tracking units arrived in January 2011, we started software development for visual stimulus presentation, eye-tracking data readout, and the data analysis.

Visual stimulus presentation and data import

A software library for adaptive visual stimulus generation, presentation, and analysis (C++ and OpenGL based) was developed in the course of the first and second quarters. This library is currently used to create visual stimuli and to collect real-time data from the eye-tracker. The data is received from the eye-tracker computer via serial connection. The library incorporates a graphical user interface, which allows to easily observe eye events and to vary the stimulus parameters.

Eye-event filters

Using the collected pilot data we designed software filters for automatic detection of the relevant eye events in real time. Altogether, 4 types of filters were developed: blinks, saccades, optokinetic reflex (nystagmus), and pupillary response (contraction/dilation). The filters are based on measuring and thresholding eye-movement velocities and pupil area changes. The filters were designed to be used with real-time data: they are fast and they do not require large amounts of data to work. About one second of data is sufficient to detect saccades and pupillary reflex, and several seconds of data – to detect optokinetic reflex (which, typically, lasts for 3 – 5 seconds at a time).

The filters were validated using human-parsed fragments of the pilot data. The collected eye-tracking data were searched and parsed into different types of relevant eye events, such as blinks, visual nystagmus, saccades, and pupil dilations. Half of the data were used to design the software filters, the other half were used for filter testing. Filter performance for the high-amplitude eye events relevant to our project was close to 100% dropping below 90% for very noisy data only. Identifying saccades was the task most affected by noise. Noisy data can result from poorly adjusted eye-tracker parameters. Such adjustments are particularly important when subjects are wearing glasses, have droopy eyelids, or narrow eyes. Altogether, the filters performance was found adequate for the purposes of our project.

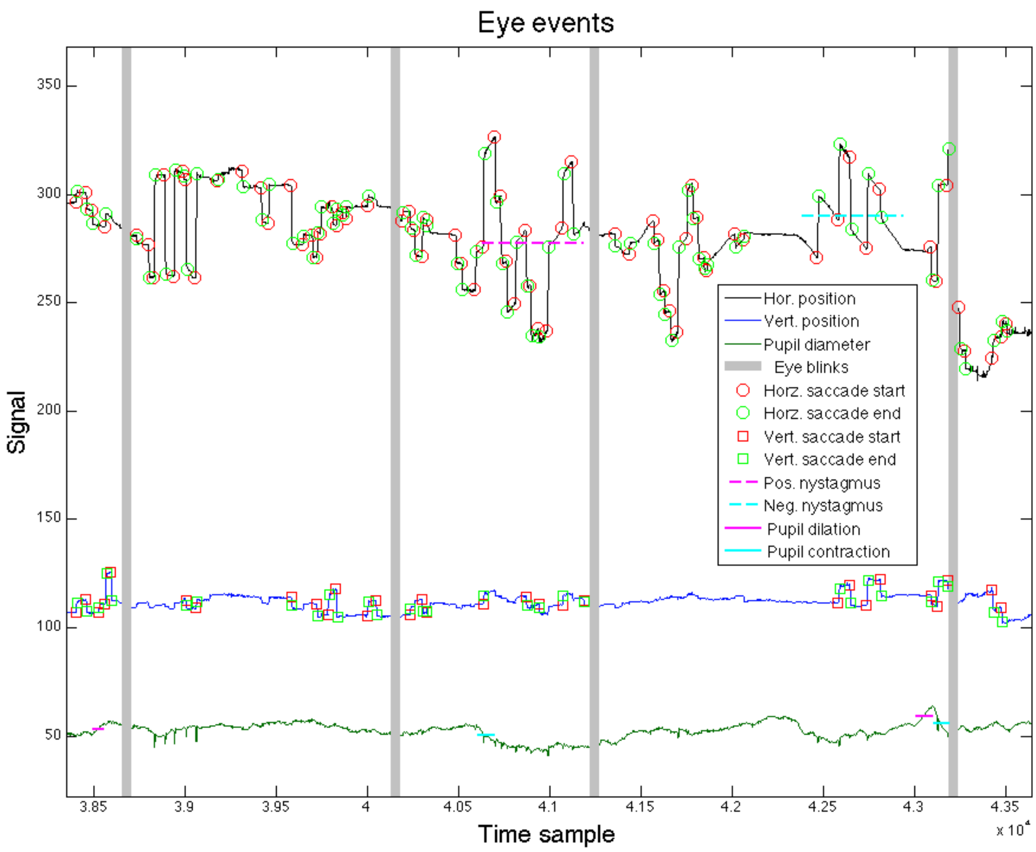

Figure 4: A fragment of raw eye-tracking data. Eye-event labels generated by software filters are overlaid on the eye position and pupil size traces.

Figure 4 illustrates the filters performance. It shows 45 seconds of raw eye-tracking data for one subject. The top (black) trace plots the horizontal eye position, the middle (blue) trace plots the vertical eye position, the bottom (green) trace plots the pupil size. Saccades appear as abrupt changes in the eye position (vertical or horizontal), nystagmus - as the sawtooth profile for the horizontal position, and pupillary reflex as a fast change in the pupil size. These events were well captured by the corresponding filters, which is demonstrated by the overlaid event symbols. For example, the last quarter of the recording (prior to the blink) shows a nystagmus event (indicated by the dashed cyan line) followed by a medium-sized horizontal saccade accompanied by a fast pupil dilation – contraction event (magenta and cyan solid lines). These events were evoked by a full-screen drifting color grating followed by one second empty screen and then a semi-nude image of Marilyn Monroe displayed in the right part of the screen.

Currently, the filter development is in its pilot stage, i.e., the filters were implemented in MATLAB and applied to off-line data only. The next stage will be to implement the filters as a part of the stimulus generation and analysis C++ software library and to test them on the data collected in real time. This stage will be completed by the end of 2011. Once this part of is in place, we shall start working on making the stimuli adaptive, the adaptation procedure being governed by the automatic eye-event registration.

Key Research Accomplishments

- After studying the market of eye-tracking solutions we identified and purchased two models, which can be used together to carry out robust eye-tracking for patients with cognitive disabilities.
- A software library for adaptive visual stimulus generation, presentation, and data acquisition was developed.
- Pilot visual stimuli were designed and tested on 26 normal observers naive to the purpose of the test. No specific instructions were given to simulate experiments with cognitively impaired observers.
- The collected data was used to optimize the visual stimulation and to design software filters which will allow automatic detection of relevant reflex eye movements in real time.

Reportable Outcomes

There were no reportable outcomes yet.

Conclusions

We successfully developed and implemented a pilot battery of tests designed to diagnose various visual dysfunctions. The principal hardware and software components of data acquisition and analysis pipeline are in place now. The visual stimulation and data collection units were tested on 26 naive observers with normal vision. We used the collected data to design software filters for automatic detection of oculomotor reflexes. These results mostly complete the first phase of the project and allow us to start the next phase, which focuses on two goals: making the developed battery of visual tests adaptive, and testing a large number of normal subjects to establish the distribution of responses for people with normal (reference) visual functions.